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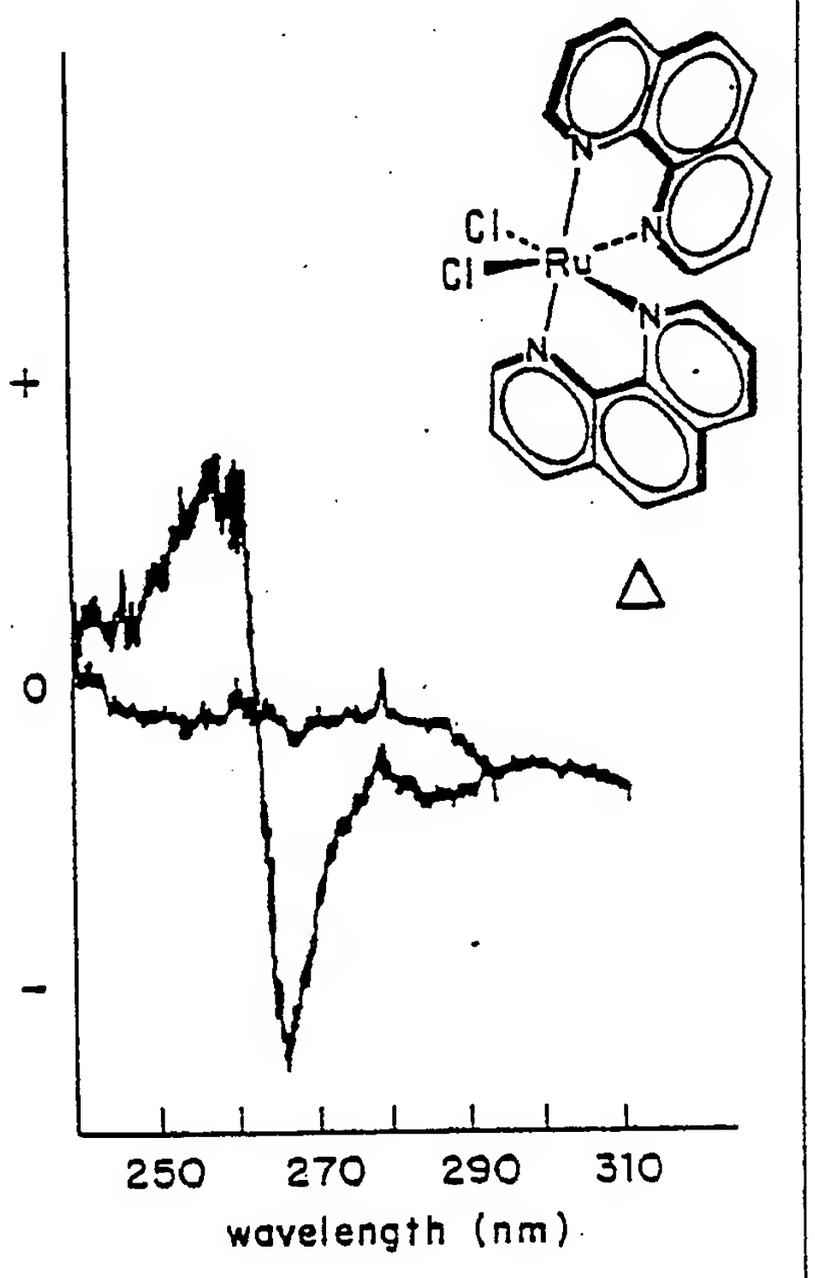
(54) Title: SITE-SPECIFIC RUTHENIUM(II) AND COBALT(III) ANTITUMOR AGENTS

(57) Abstract

A coordination complex of the formula $(R)_2$---M---$(Y)_2$ wherein M comprises a suitable transition metal, e.g. cobalt or ruthenium, R comprises 1,10-phenanthroline or a substituted derivative thereof, Y comprises a labile ligand, e.g. chloride, tartrate, malonate or ascorbate ion and R and Y are bonded to M by coordination bonds. A complex of this invention may be used for covalently labeling DNA with a complex of the formula $(R)_2$---M, wherein R and M are as previously defined. A complex of this invention which contains cobalt may also be used in a method for nicking DNA by effecting single-stranded scission of at least one phosphodiester bond of the DNA with ultraviolet radiation. A complex of this invention is further useful in a method for killing tumor cells. A pharmaceutical conposition for the treatment of tumor cells in a subject may be prepared containing an effective anti-tumor amount of a complex of this invention and a pharmaceutically acceptable carrier. Such a composition may be used for treating a subject afflicted with tumor cells so as to cause regression of the tumor cells.



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SITE-SPECIFIC RUTHENIUM(II) AND COBALT(III) ANTITUMOR AGENTS

The invention described herein was made with government support under grant number GM 33309 from the National Institutes of Health, United States Department of Health and Human Services. The government has certain rights in this invention.

Background of the Invention

Throughout this application various publications are referenced by arabic numerals within parentheses. Full citations for these publications may be found at the end of the specification immediately preceding the claims. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art to which this invention pertains.

Recently there has been increased attention focused on the binding of metal complexes to nucleic acids and nucleic acid constituents (1). This interest stems in large part from the successful application of cis-dichlorodiammineplatinum(II) (cis-DDP or cisplatin) as an antitumor drug (2). See also, U.S. Patent Nos. 4,273,755 (1981); 4,302,446 (1981); 4,310,515 (1982); 4,339,437 (1982) and 4,451,447 (1984). More recently chiral transition metal complexes have been utilized in designing specific probes for nucleic acid structure. The tris(phenanthroline) complexes of zinc(II) (3) and ruthenium(II) (4) display enantiomeric selectivity in binding to DNA by intercalation. Because of their high specificity in intercalative binding to right- or left-handed DNAs, enantiomers of tris(4,7-

diphenylphenanthroline) ruthenium(II) and cobalt(III) provide respectively spectroscopic probes (5) and cleaving agents (6) that are DNA conformation-specific. Such complexes bind to DNA only under suitable intercalating conditions, and do not bind to DNA in a covalent fashion.

It has now been discovered that certain bis-substituted metal complexes of phenanthrolines are capable of binding covalently and stereospecifically to DNAs. Such complexes are useful in stereospecific labeling and cleavage of DNAs and are further useful as antitumor agents.

Summary of the Invention

This invention involves a coordination complex of the formula $(R)_2---M---(Y)_2$ wherein R comprises 1,10-phenanthroline or a substituted derivative thereof; M comprises a suitable transition metal, e.g. ruthenium or cobalt; Y comprises a labile ligand, e.g. chloride, tartrate, malonate or ascorbate ion; and R and Y are bonded to M by coordination bonds.

This invention also concerns a method for covalently labeling DNA with a complex of the formula $(R)_2---M$, where R and M are as defined above. This method involves contacting the DNA with a complex of this invention under suitable binding conditions such that complex covalently binds to the DNA.

This invention further concerns a labeled DNA molecule comprising DNA to which a complex of the formula $(R)_2---M$ is covalently bound wherein R comprises 1,10-phenanthroline or a substituted derivative thereof, M comprises a transition metal, e.g. ruthenium or cobalt, and R is bonded to M by a coordination bond.

This invention further concerns a method for nicking DNA by effecting single-stranded scission, i.e. breakage of at least one of the phosphodiester bonds along the DNA. This method involves contacting the DNA with a cobalt-containing complex of this invention under suitable binding conditions such that the complex covalently binds to the DNA to form an adduct and irradiating the adduct so formed with a sufficient dose of ultraviolet radiation of an appropriate wavelength to nick the DNA. An appropriate wavelength for the ultraviolet radiation of this method is a wavelength of

ultraviolet radiation absorbed by the ligand bands of the complex used.

Another embodiment of this invention is a method for killing a portion of a population of appropriate tumor cells. This method involves contacting the tumor cells under suitable conditions with an effective amount of a coordination complex of this invention to kill the tumor cells. Where the tumor cells are present in a subject, e.g. a human or animal, the contacting may suitably be effected by administering the coordination complex to the subject. Where the complex used in this embodiment is a cobalt-containing complex the method may further involve irradiating the tumor cells with a suitable dose of ultraviolet radiation of an appropriate wavelength at a suitable time after the tumor cells have been contacted with the complex, permitting the complex to nick DNA.

This invention further involves a pharmaceutical composition for the treatment of tumor cells in a subject which comprises an effective antitumor dose of a complex of this invention and a pharmaceutically acceptable carrier.

This invention additionally concerns a method for treating a subject, e.g. a human or animal, afflicted with tumor cells so as to cause regression of the tumor cells. This method involves administering to the subject by a suitable route a pharmaceutical composition of this invention in an amount sufficient to cause regression of the tumor cells. Administration may be parenteral or may be topical. Furthermore as in previous embodiments, where the complex is a cobalt-containing complex the method may further involve irradi-

ating the tumor cells with a suitable dose of ultraviolet radiation of an appropriate wavelength. In this method the tumor cells may be irradiated at a suitable time after administration of the pharmaceutical composition to the subject permitting the complex to nick DNA.

Brief Description of the Figures

Figure 1. Plot of (1,10-phenanthroline)$_2$RuCl$_2$ binding to calf thymus DNA as a function of time; r is the ratio of bound ruthenium to nucleotide concentrations.

Figure 2. Circular dichroism of the supernatant after ethanol precipitation of the ruthenium complex bound to B-DNA. Binding to B-DNA is stereoselective and leads to enrichment of the supernatant in the unbound delta isomer (inset).

Detailed Description of the Invention

The present invention involves a coordination complex of the formula $(R)_2$---Co(III)---$(Y)_2$ wherein R comprises 1,10-phenanthroline or a substituted derivative thereof; Y comprises a labile ligand, e.g. chloride, tartrate, malonate or ascorbate ion, and R and Y are bonded to the Co(III) by coordination bonds. A "substituted derivative" as the phrase is used herein is a compound obtained by replacing one or more hydrogen atoms present in 1,10-phenanthroline with one or more moieties having the characteristic that the complex containing the resulting compound binds to DNA. Merely by way of example, the substituted derivative of 1,10-phenanthroline may be 4,7-diamino-1,10-phenanthroline; 3,8-diamino-1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline or 3,8-dispermine-1,10-phenanthroline. Unless otherwise specified, the complex of this invention is a racemic mixture of enantiomers.

Several such complexes including bis(1,10-phenanthroline)ruthenium(II) dichloride, bis(4,7-diphenyl-1,10-phenanthroline)-ruthenium(II) dichloride, and bis(4,7-diphenyl-1,10-phenanthroline)cobalt(III) tartrate have been prepared and their DNA-binding properties studied. Each of these neutral species is chiral, octahedral, and contains two inert ligands (the diamines) and two labile ligands in a cis-orientation.

One embodiment involves a method for covalently labeling DNA with a complex of the formula $(R)_2$---M where R is as defined above, M in this and other embodiments of the invention is a suitable transition metal, i.e. a transition metal capable of forming an octahedral complex with 1,10-phenanthroline or a substituted derivative thereof and R is bound to M by a coordination bond. Presently preferred transition metals are ruthenium(II) and cobalt(III). According to this method the DNA is contacted with a complex of the formula $(R)_2$---M---$(Y)_2$, where R, M and Y are as defined above, the contacting being under suitable conditions such that the $(R)_2$---M complex covalently bonds to the DNA.

The invention also concerns a labeled DNA molecule comprising DNA to which a complex of the formula $(R)_2$---M as defined previously, is covalently bound. Preferably, the labeled DNA is produced by the method described above.

A further embodiment of this invention concerns a method for nicking DNA by effecting single-stranded scission, i.e. breakage, of at least one phosphodiester bond along the DNA. This method involves contacting the DNA with a cobalt(III)-containing complex of the formula $(R)_2$---Co(III)---$(Y)_2$, as previously defined, the contacted being under suitable conditions such that the $(R)_2$---Co(III) complex covalently binds to the DNA to form an adduct. The adduct so formed is then irradiated with a sufficient dose of ultraviolet radiation of an appropriate wavelength to nick the DNA. In this and other embodiments an appropriate wavelength is a wavelength of ultraviolet radiation which is absorbed by the ligand bands of the complex used.

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sition as described above in an amount sufficient to cause regression of the tumor cells. Suitable routes of administration include parenteral administration and topical administration, e.g. in cases such as skin cancers where the tumor cells are located on or near an exposed surface of the subject. Furthermore, if the complex used is a cobalt(III)-containing complex, the method may additionally involve irradiating the tumor cells with a suitable dose of ultraviolet radiation of an appropriate wavelength permitting the complex to nick DNA. In this method the irradiation should be conducted at a suitable time after administration of the composition to the subject, i.e. to permit the complex to interact with the DNA.

Experimental Details

Unlike the corresponding tris-substituted complexes, the bis-analogues of this invention are not coordinatively saturated. The cis-oriented chlorides are good leaving groups, permitting DNA base substitution at those positions. Indeed the aqueous chemistry of ruthenium(II), and bis(1,10-phenanthroline)dichlororuthenium(II) [also referred to as $(phen)_2RuCl_2$] in particular, resembles reactions of platinum(II). The complex $(phen)_2RuCl_2$ binds covalently to DNA. The neutral ruthenium complex moreover shows similarities to the anticancer drug cis-dichlorodiammineplatinum(II) (cis-DDP) in its binding characteristics, with respect to rates of reaction, DNA conformational changes, and the preferential binding to guanine sites. The ruthenium complex offers two potentially interesting advantages. First, the enantiomers show chiral selectivity. The complexes represent covalent-binding analogues to the chiral tris-phenanthroline cations. One enantiomer binds preferentially to right-handed B-DNA. The other enantiomer binds to left-handed DNA preferentially and even converts sequences from the B- to Z-form. Secondly the organic ligand framework for these octahedral complexes permits additional specificity to be built in. Thus the stereochemistry in these ruthenium complexes provides a basis for the design of site-specific covalent binding drugs.

One illustrative embodiment, namely $(phen)_2RuCl_2$, binds covalently to the DNA duplex and exhibits striking enantiomeric selectivity, different from that observed in the intercalation of corresponding $M(phen)_3$ complexes with DNA.

In one experiment, racemic $(phen)_2RuCl_2$ (7) (50 μM) was incubated in buffer containing 10% ethanol, 50 mM $NaNO_3$, 5 mM Tris at pH 7.1, either at ambient temperatures or 37°C for variable amounts of time with calf thymus DNA (500 μM nucleotide) (8). Immediately after the incubation period, NaCl and 95% ethanol were added to quench the reaction and precipitate the DNA. Unbound ruthenium, more soluble in the ethanol supernatant, remained in solution. After centrifugation, the supernatant was assayed spectrophotometrically, compared to controls lacking ruthenium or DNA, and levels of bound and free metal complex were determined. This experiment measured only covalent binding to the DNA.

The procedure was repeated using the coordinatively saturated tris(phenanthroline) ruthenium cation, $(phen)_3Ru^{2+}$, which binds to DNA by intercalation (4). Under these assay conditions no binding to DNA was observed. A plot of the extent of coordination to DNA by the $(phen)_2Ru^{2+}$ cation as a function of time is shown in Figure 1. A maximum binding ratio of 0.045, or one $(phen)_2Ru^{2+}$ moiety for every 11 base pairs, is obtained at about 3 1/2 hours. This dependence on time likely reflects both the kinetics of hydrolysis of $(phen)_2RuCl_2$ and ligand substitution (9), e.g. the association of the metal complex with the DNA.

Significant enantiomeric discrimination accompanies this covalent binding. The circular dichroism of the supernatant, the unbound fraction, is shown in Figure 2. The solution is appreciably enriched in the less favored isomer. Optically enriched $(phen)_2RuCl_2$ solutions have not been obtained previously using more conventional methods. While the rate of racemization

of the complexes of this invention is slow in the buffer system used, significant solvent dependence in the racemization rate has been observed. These observations support similar observations previously reported (10). The magnitude of the rotation in the ultraviolet region is approximately 5 times larger than that seen earlier for $(phen)_3Ru^{2+}$ solutions at comparable levels of intercalative binding. Hence, the degree of chiral selectivity for this covalent adduct appears substantially greater than for $(phen)_3Ru^{2+}$. Based upon exciton theory (11), it was expected that the rotational strength of pure enantiomers of $(phen)_2RuCl_2$ in the vicinity of the ligand absorption would be one half that of $(phen)_3RuCl_2$. Since pure enantiomers of $(phen)_2RuCl_2$ have not been isolated, the relative ratio of affinities of the two enantiomers has not yet been determined. The absolute configuration of the isomer preferred has, however, been assigned. Based upon simple exciton theory (11) and the identical circular dichroism (CD) in the ultraviolet region to that for $(phen)_3Ru^{2+}$ (12), the CD given in Figure 2 has been assigned to the delta isomer. In contrast to the binding specificity seen with $(phen)_3Ru^{2+}$, it is lambda-$(phen)_2Ru^{2+}$ that binds preferentially to B-DNA.

The enantiomeric discrimination of the bis(phenanthroline)ruthenium complex in binding to B-DNA must therefore differ from tris(phenanthroline) cation not only in degree but also in the structural basis for the stereoselectivity. Ruthenium(II) complexes have a high affinity for the heterocyclic bases of DNA (14). A likely site of metallation would be the N-7 atom of guanine, which is readily accessible in the major groove of the DNA duplex. Initial intercalation is probable; immediate hypochromic changes in the rutheni-

um charge transfer band are evident upon the addition of DNA. However further spectroscopic changes become evident on a time scale comparable to the binding given in Figure 1 and these changes must reflect covalent binding to the helix. From an initially intercalated position, the lambda isomer is well oriented for covalent binding to base positions above and below. Model building shows that the delta isomer cannot be similarly aligned for covalent binding, since the other non-stacked phenanthroline ligand is considerably crowded by the right-handed helical column (base and sugar-phosphate groups). This bifunctional coordination oriented by initial intercalation could account for the high stereoselectivity observed. It is interesting that in the case of intercalation by $(phen)_3Ru^{2+}$, the delta isomer, which has the same helical screw sense as the right-handed B-DNA, is preferred, while here metallation of base positions seems to require the lambda configuration, that is a structure <u>complementary</u> to the B-DNA helix.

Recently the photoactivated stereospecific cleavage of DNA by chiral tris-substituted phenanthroline complexes of Cobalt(III), e.g. the tris (4,7-diphenyl-1,10-phenanthroline) or "DIP" cobalt complexes, has been reported (6). The corresponding chiral bis enantiomers, e.g. bis(DIP)Co(III) tartrate, which have DNA binding properties analogous to those of the corresponding bis-ruthenium complexes have now been found to cleave DNA photochemically and at sites different from $(DIP)_3Co^{+3}$. Bis(DIP)Co(III) for example may cleave DNA specifically at homopurine sites upon ultraviolet irradiation.

The stereoselective covalent binding to DNA of $(phen)_2RuCl_2$, substituted analogs thereof, e.g. the bis-DIP complex, and the corresponding cobalt analogues likely has significant biological consequences. The neutral $(phen)_2RuCl_2$, for example, may be considered an octahedral analogue for cis-$Pt(NH_3)_2Cl_2$ (14). Results from laboratories in Australia more than ten years ago which indicated antibacterial, virostatic, and antileukemic activity in vitro of tris unsubstituted phenanthroline complexes of ruthenium(II) (15); recent reports of antitumor activities and toxicities of various ruthenium complexes (1,15), the possible similarities between $Ru(phen)_2Cl_2$ and cis-DDP in interactions with DNA; and the striking stereoselectivity observed with the complexes of this invention all support potential chemotherapeutic application of these chiral complexes.

Complexes of this invention have in fact been screened with respect to cytotoxicity, and the results presented in Table I show the complexes to be highly potent in vitro. Additionally, the cobalt complexes of this invention may exhibit photochemical activation with ultraviolet irradiation.

These compounds are potentially very effective antitumor drugs. The advantages such compounds provide over cis-platin include lower heavy-metal toxicity, greater selectivity owing to stereochemistry, greater site specificity given the organic ligands (not present in cis-platin) and the possibility of linkage to monoclonal antibodies, and easier and less expensive preparation. Furthermore the cobalt(III) nicking activity may permit localization by photolysis in vivo.

Table I

Cytotoxicity Results of Cobalt and Ruthenium Complexes

Compound	Cell Line[a]	ID_{50} (µg/ml)[b]
$Ru(phen)_2Cl_2$	L1210	4.7
	P815	7.0
$Ru(DIP)_2Cl_2$	L1210	3.2
	P815	3.5
$Co(DIP)_2Cl_2$	L1210	0.44
	P815	0.48

a L1210 and P815 are mouse leukemia cell lines

b determined by the method of Burchenal, J.H. et al., CANCER RESEARCH 42:2598-2600 (1982)

Experimental Method and Materials

Phenanthroline Complexes

Racemic $(phen)_2Ru(II)Cl_2$ was prepared as follows: To a solution of 3mmoles $RuCl_3 \cdot 3H_2O$ in 30 ml dimethylformamide was added 6 mmoles phenanthroline monohydrate. The solution was allowed to reflux for 3h during which time the solution turned a deep violet in color. After being reduced in volume to about 20 ml, the solution was cooled at 0°C and a deep black solid as crude product was obtained. The product was recrystallized twice from 100 ml 50% ethanol saturated with lithium chloride. Racemic mixtures of other complexes of this invention were prepared by analogous methods substituting the appropriate 1,10-phenanthroline compound for 1,10-phenanthroline. See also (7): 1,10-phenanthroline, 4,7-diphenyl-1,10-phenanthroline, and other chemical reagents were obtained from Aldrich Chemical Co., St. Louis, Missouri.

Spectroscopic data for $Ru(phen)_2Cl_2$ in ETOH was as follows:

$\varepsilon = 1.08 \times 10^4 M^{-1}cm^{-1}$ at 496 nm; $\varepsilon = 7.25 \times 10^4 M^{-1}cm^{-1}$ at 267 nm. In aqueous solution the complex may be considered a mixture of hydrolyzed species.

Bis (4,7-diphenyl-1,10-phenanthroline)cobalt(III) chloride, $(DIP)_2Co(III)Cl_2$, was prepared as follows: 4,7-diphenyl-1,10-phenanthroline (Aldrich) was dissolved in a minimum volume of ethanol to which one half stoichiometric $CoCl_2 \cdot 6H_2O$ was added. The green-brown solution was oxidized by using Br_2/H_2O, and a heavy orange precipitate formed immediately. The solution was refluxed for 1h, and concentrated hydrochloride was added. The

bromine oxidation was then repeated. The crude complex was recrystallized in aqueous ethanol. Other cobalt(III) complexes of this invention may be prepared by this method by substituting the appropriate ligand for 4,7-diphenyl-1,10-phenanthroline.

Buffers and DNA

Calf thymus DNA was obtained from Sigma Chemical Company, St. Louis, Missouri and purified by phenol extraction using previously described methods (8). DNA concentrations per nucleotide were determined spectrophotometrically by assuming $\epsilon_{260}6000M^{-1}cm^{-1}$ (18). Buffers were also obtained from Sigma.

DNA cleavage

The cobalt complex is added to the DNA sample in a solution buffered to about 7.1 e.g., in buffer containing 10% ethanol, 50 mM $NaNO_3$, 5 mM Tris at pH 7.1, either at ambient temperature or 37°C. The solution is then irradiated at 315 nm with a 1000 W Hg/xenon lamp (narrowed to 315±5 nm with a monochrometer) for about 90 seconds to about 1 hour and the precipitate washed with ethanol.

In vitro screening

For cell culture studies, a modification of the technique of Fischer (4) was used. The cells were incubated in McCoy's Medium 5A with 15% fetal calf serum. The initial inoculum was 40,000 to 60,000 leukemic cells/ml. For studies of the inhibition of cell growth, 0.1 ml of a 20-fold concentration of the drug in question was added to 2 ml of media containing 4 X

10^4 cells/ml in Linbro tissue culture multiwell plates and allowed to incubate at 37° in 5% CO_2 for 96 hours. By this time, growth to approximately 10^6 cells/ml occurred in the control wells. The contents of each well were agitated to resuspend the cells and counted on a Coulter Counter. The percentage of inhibition of growth and the concentrations inhibiting cell growth by 50% were calculated. Cell culture experiments were done with mouse leukemia cell lines L1210 and P815 which may be obtained from the American Type Culture Collection (ATCC), Rockville, Maryland.

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What is Claimed is:

1. A coordination complex of the formula $(R)_2$---Co(III)---$(Y)_2$, wherein R comprises 1,10-phenanthroline or a substituted derivative thereof; Y comprises a labile ligand and Y and R are bonded to the Co(III) by coordination bonds.

2. A complex of claim 1, wherein Y is a chloride, tartrate, malonate or ascorbate ion.

3. A complex of claim 1, wherein the substituted derivative of 1,10-phenanthroline comprises 4,7-diamino-1,10-phenanthroline; 3,8-diamino-1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline, or 3,8-dispermine-1,10-phenanthroline.

4. A method for covalently labeling DNA with a complex of the formula $(R)_2$---M wherein R comprises 1,10-phenanthroline or a substituted derivative thereof, M comprises a suitable transition metal, and R is bonded to M by a coordination bond, which comprises contacting the DNA with a complex of the formula $(R)_2$---M---$(Y)_2$, wherein Y is a labile ligand and is also bonded to M by a coordination bond, the contacting being under suitable conditions such that the complex covalently binds to the DNA.

5. A method of claim 4, wherein M is ruthenium(II).

6. A method of claim 4, wherein M is cobalt(III).

7. A method of claim 4, wherein the substituted derivative of 1,10-phenanthroline comprises 4,7-diamino-1,10-phenanthroline; 3,8-diamino-1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline; or 3,8-dispermine-1,10-phenanthroline.

8. A labeled DNA molecule comprising DNA to which a complex of the formula $(R)_2$---M is covalently bound, wherein R comprises 1,10-phenanthroline or a substituted derivative thereof, M comprises a suitable transition metal and R is bonded to M by a coordination bond.

9. A labeled DNA molecule of claim 8, wherein M is ruthenium(II).

10. A labeled DNA molecule of claim 8, wherein M is cobalt(III).

11. A labeled DNA molecule of claim 8, wherein the substituted derivative of 1,10-phenanthroline comprises 4,7-diamino-1,10-phenanthroline; 3,8-diamino-1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline, or 3,8-dispermine-1,10-phenanthroline.

12. A DNA molecule labeled with a complex of the formula $(R)_2$---M wherein R is 1,10-phenanthroline or a substituted derivative thereof, M is a suitable transition metal and R is bonded to M by a coordination bond, the labeled DNA molecule being produced by the method of claim 4.

13. A method for nicking DNA by effecting breakage of at least one phosphodiester bond along the DNA which comprises contacting the DNA with a complex of claim 1 under suitable conditions such that the complex covalently binds to the DNA to form an adduct and irradiating the adduct so formed with a sufficient dose of ultraviolet radiation of an appropriate wavelength to nick the DNA.

14. A method for killing a portion of a population of appropriate tumor cells which comprises contacting the tumor cells under suitable conditions with an effective amount of a coordination complex of the formula $(R)_2$---M---$(Y)_2$ to kill the tumor cells, wherein R comprises 1,10-phenanthroline or a substituted derivative thereof, M comprises a suitable transition metal; Y comprises a labile ligand and Y and R are bonded to M by coordination bonds.

15. A method of claim 14, wherein M is ruthenium(II).

16. A method of claim 14, wherein M is cobalt(III).

17. A method of claim 14, wherein the substituted derivative of 1,10-phenanthroline comprises 4,7-diamino-1,10-phenanthroline; 3,8-diamino-1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-

diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline, or 3,8-dispermine-1,10-phenanthroline.

18. A method of claim 14, wherein the tumor cells are present in a subject and the contacting is effected by administering the coordination complex to the subject.

19. A method of claim 16 which further comprises irradiating the tumor cells with a suitable dose of ultraviolet radiation of an appropriate wavelength at a suitable time after the tumor cells have been contacted with the complex, permitting the complex to nick DNA.

20. A pharmaceutical composition for the treatment of tumor cells in a subject which comprises an effective anti-tumor amount of a complex of the formula $(R)_2$---M---$(Y)_2$ and a pharmaceutically acceptable carrier, wherein R comprises 1,10-phenanthroline or a substituted derivative thereof, M comprises a suitable transition metal; Y comprises a labile ligand and Y and R are bonded to M by coordination bonds.

21. A pharmaceutical composition of claim 20, wherein M is ruthenium(II).

22. A pharmaceutical composition of claim 20, wherein M is cobalt(III).

23. A pharmaceutical composition of claim 20, wherein the substituted derivative of 1,10-phenanthroline comprises 4,7-diamino-1,10-phenanthroline; 3,8-diamino-

1,10-phenanthroline; 4,7-diethylenediamine-1,10-phenanthroline; 3,8-diethylenediamine-1,10-phenanthroline; 4,7-dihydroxyl-1,10-phenanthroline; 3,8-dihydroxyl-1,10-phenanthroline; 4,7-dinitro-1,10-phenanthroline; 3,8-dinitro-1,10-phenanthroline; 4,7-diphenyl-1,10-phenanthroline; 3,8-diphenyl-1,10-phenanthroline; 4,7-dispermine-1,10-phenanthroline, or 3,8-dispermine-1,10-phenanthroline.

24. A method for treating a subject afflicted with tumor cells so as to cause regression of the tumor cells which comprises administering to the subject by a suitable route a composition of claim 20 in an amount sufficient to cause regression of the tumor cells.

25. A method for treating a subject afflicted with tumor cells so as to cause regression of the tumor cells which comprises administering to the subject by a suitable route a composition of claim 21 in an amount sufficient to cause regression of the tumor cells.

26. A method for treating a subject afflicted with tumor cells so as to cause regression of the tumor cells which comprises administering to the subject by a suitable route a composition of claim 22 in an amount sufficient to cause regression of the tumor cells.

27. A method for treating a subject afflicted with tumor cells so as to cause regression of the tumor cells which comprises administering to the subject by a suitable route a composition of claim 23 in an amount sufficient to cause regression of the tumor cells.

28. A method of claim 24, wherein the route of administration is parenteral.

29. A method of claim 24, wherein the route of administration is topical.

30. A method of claim 26 which further comprises irradiating the tumor cells with a suitable dose of ultraviolet radiation of an appropriate wavelength permitting the complex to nick DNA at a suitable time after the administration of the composition to the subject.

FIG. 1

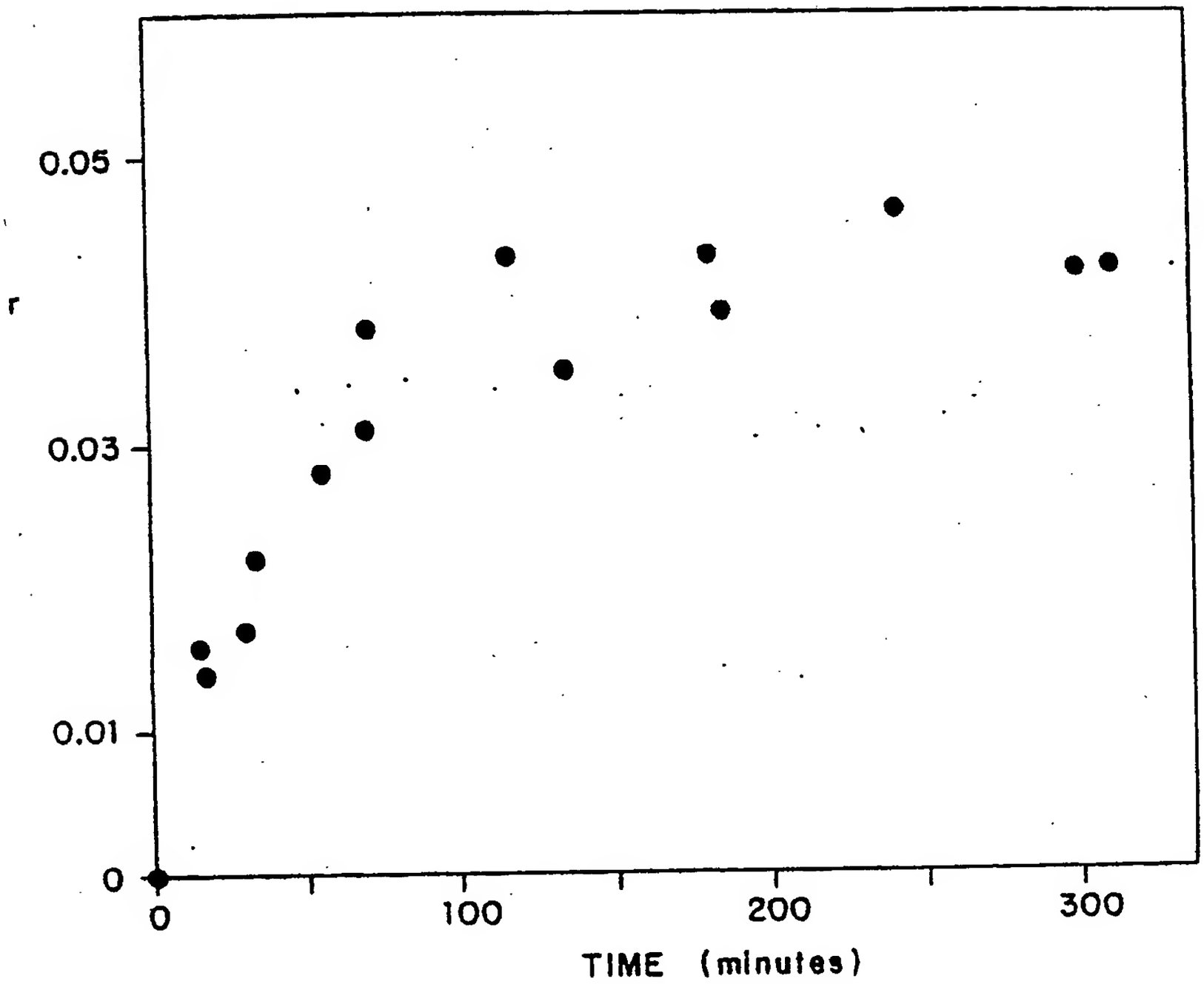
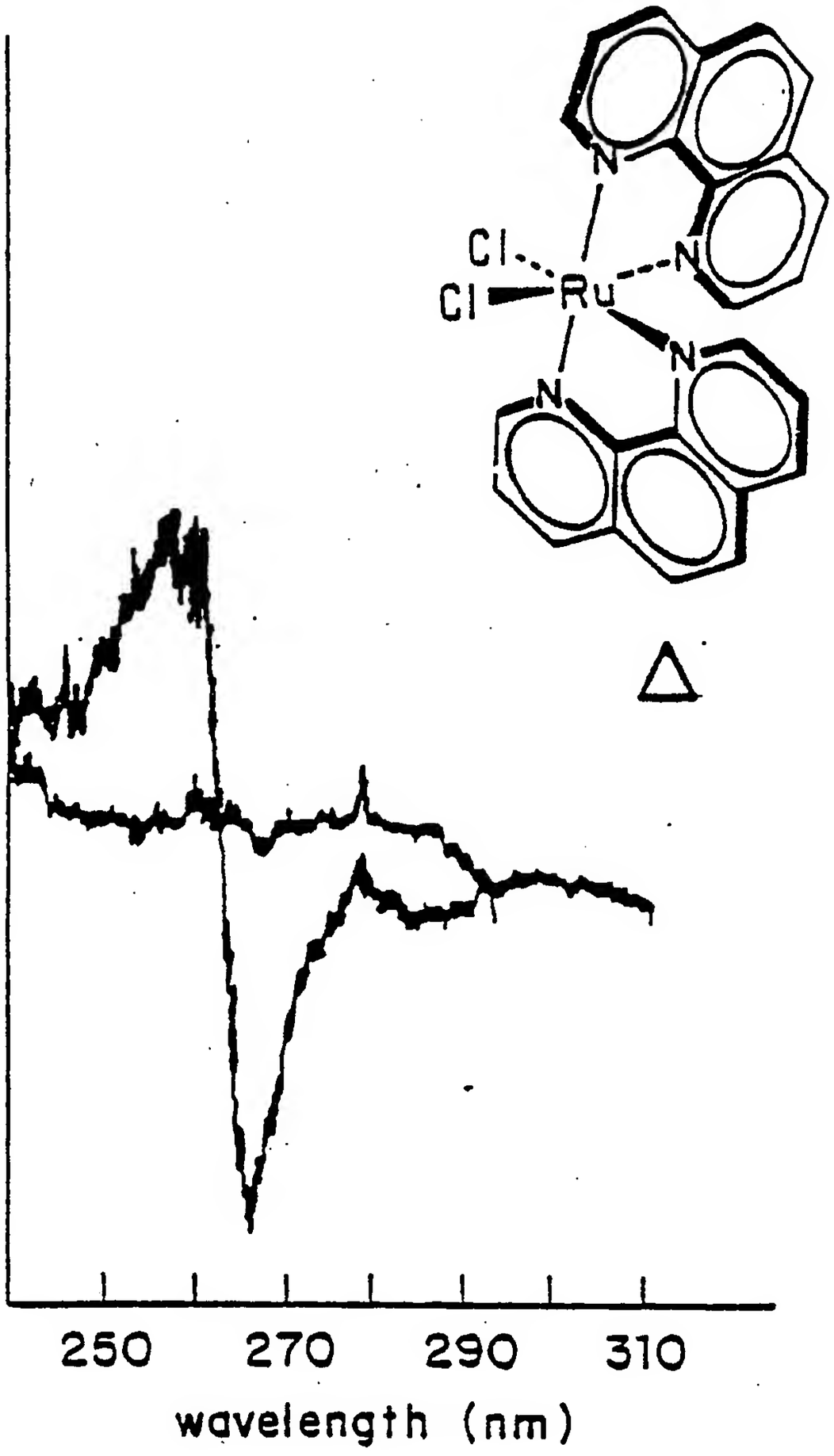


FIG. 2



INTERNATIONAL SEARCH REPORT

International Application No PCT/US86/00108

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[4] C12Q 1/68; C07D 471/04; A61K 33/24
U.S. CL. 435/6; 546/88; 424/131

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	424/1.1, 9, 131, 149 546/10, 88 435/6 556/136, 138 536/27, 28, 29 935/77,78

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [5]

Chemical Abstracts: 1967-1986 April
Medline: 1966-1986 April
Biosis: 1981-1986 April

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 4,273,755 Published 16 June 1981, Rhoda et al.	1-30
Y	US, A, 4,302,446 Published 24 November 1981, Kaplan et al.	1-30
Y	US, A, 4,310,515 Published 12 January 1982, Granatek et al.	1-30
Y	US, A, 4,339,437 Published 13 July 1982, Rosenberg et al.	1-30
Y	US, A, 4,451,447 Published 29 May 1984, Kaplan et al.	1-30
P, X	N, J. Am. Chem. Soc. Issued 1985, Barton et al. Chiral discrimination in the covalent binding of bis(phenanthroline)-dichlororuthenium(II) to B-DNA. 107: 708-709.	1-30
Y	N, J. Am. Chem. Soc., Issued 1984, Barton et al. Tris(phenanthroline)ruthenium(II) Stereoselectivity in binding DNA.	1-30

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
02 April 1986	10 APR 1986
International Searching Authority [1]	**Signature of Authorized Officer** [20]
ISA/US	Cynthia Lee Foulke

Form PCT/ISA/210 (second sheet) (October 1981)

III. D CUMENTS CONSIDERED T BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, 16 with indication, where appropriate. of the relevant passages 17	Relevant to Claim No 18
Y	N, J. Am. Chem. Soc. Issued 1982, Barton et al. Enantiomeric Selectivity in binding tris (phenathroline) zinc (II) to DNA. 104:4967-4969.	1-30
A	N, J. of Biol. Chem. Issued 25 October 1982, Pope et al. Products of DNA cleavage by the 1,10-phenanthroline-copper complex. 257(20):12121-12128.	1-30
A	N, Inorg. Chem. Issued 1980, Clarke, Mutagenicity and modes of metal binding to nucleic acids. 19:1103-1104.	
A	N, J. Am Chem. Soc. Issued 12 September 1979, 1979, Graves et al. Metal Ion Coordination to the exocyclic amine in a pyrimidine complex. 101(19):5608-5612.	
Y	N, Inorg. Chem. Issued 1978, Sullivan et al. Mixed phosphine 2,2'-bipyridine complexes of ruthenium. 17(12):3334-3341.	1-30
A	N, Inorg. Chem. Issued 1977, Clarke, Linkage isomers of pentaammineruthenium-hypoxanthine complexes 16(4): 738-744.	
A	N, J. Am. Chem. Soc. Clarke et al. Issued 21 August 1974. Pentaam mineruthenium-guanine complex 96:5413-5419.	
Y	N, Nature. Issued 26 April 1969 Rosenberg. Platinum compounds: a new class of potent antitumour agents. 222:385-386.	1-30